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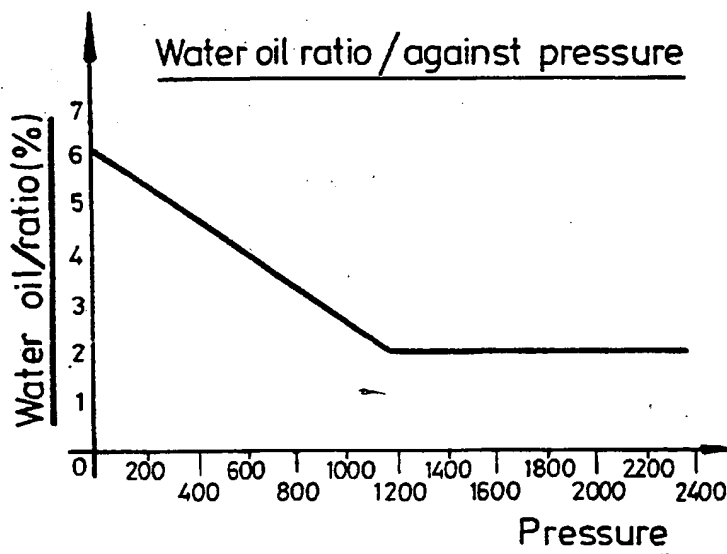
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(54) Title: APPARATUS AND A METHOD FOR MEASURING FLOW RATE



(57) Abstract

Apparatus and a method for measuring flow rate is described which allows measurement of the flow rate of separate phases of a multi-phase fluid. In one embodiment two flowmeters (12, 18) are disposed in series separated by a choke or orifice plate (16). The choke (16) causes the gas phase to break from the oil phase. Bulk flow rate is measured before and after the orifice plate and density meters (32, 34) measure the fluid density at each flowmeter to give the oil/water ratio values before and after the orifice plate (16). From this data the bulk flow rates at atmospheric conditions can be determined for each phase. Alternative embodiments of the invention are described.

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APPARATUS AND A METHOD FOR MEASURING FLOW RATE

This invention relates to apparatus and a method for measurement of the rate of flow of hydrocarbon products from a reservoir.

In order to determine the deliverability and commerciality of a reservoir it is necessary to compare the reservoir pressure characteristics against the volume of well fluids produced; this enables the boundaries, permeability and porosity of the reservoir to be determined.

Fluid extracted from a reservoir frequently exists in more than one phase and it is desirable to know the individual flow rates of the separate phases, for example, in the case of oil extraction from a reservoir, quantities of water and gas will be recovered in addition to the oil.

The flow rates of fluid recovered are monitored utilising a test separator. Products extract are passed through the test separator and are split by gravitational effects into the individual components and the flow rate of each component is measured. This technique for measuring flow rates is somewhat limited; for example, a normal production platform can have as many as 40 producing wells but because of space and weight restrictions only one test separator may be installed. Hence the actual flowing parameters of each well will only

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be available for analysis for circa 1/40th of the life of a well so that the depletion and productivity information obtained will be severely limited.

Furthermore, prior to placing a platform and establishing production facilities it is necessary to establish the productivity of the reservoir. This is achieved by drilling and testing of exploration and appraisal wells. To test these a large quantity of mobile test equipment has to be installed upon the rig which is a time consuming and expensive operation requiring high numbers of personnel to install and operate the equipment.

Flow meters which measure a single phase fluid are well known, two of the most common types being a venturi meter and an orifice meter. By measuring the gravity of the fluid and the differential pressure created across the meter accurate flow rates can be determined. Recent advances in the technology have seen these systems installed in the lower portion of the well conduit, where the pressure of the extract products is particularly high and the gas component is dissolved in the liquid phase. It is particularly preferred, for this reason, that the pipe section in which the flow meter is incorporated is positioned at a location at which the pressure is greater than the bubble point pressure of the liquid so that the product whose flow rate is being measured consists only of liquid (the gas portion being an immiscible component).

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A meter which is capable of measuring all produced phases without recourse to the separation of these phase would be highly desirable. Published international patent application No 91/15738 discloses a device for measuring multi-phase fluid flow which includes first and second flow meters connected in series for measuring first and second fluid flows. This device discloses flowmeters which have impellers which are rotated by the movement of fluid past them. These impellers obstruct flow and lead to inaccurate calculation of separate phase flow rates. In addition, the density of the fluid is not measured at each flowmeter but an average density is measured and requires a vertical container. This spatial orientation is a considerable disadvantage in locating such equipment offshore and the average density value leads to inaccurate results which compound inaccuracies from the impeller type flowmeters.

An object of the present invention is to provide a method and apparatus for measuring the flow rate of each phase of a multi-phase fluid, particularly a 3-phase fluid, which obviates or at least one of the aforementioned disadvantages.

This is achieved by providing two flow meters in series or in parallel with a choke or orifice associated with said flowmeters which can be used in any orientation and which have density meters associated with each flow meter. Flow measurements in the first flow meter yield a first bulk flow rate value.

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The choke causes a gas phase to break from the oil phase resulting in a total fluid volume increase and velocity increase and the second bulk flow rate is measured in the second flow meter. A comparison of the initial to secondary bulk flow rate and a change of water/oil ratio is used to provide the total flow rate of each phase and, using appropriate calculations, flow rate at atmospheric conditions for each phase can be obtained. Density meters are coupled to the primary and secondary flow meters for measuring value fluid density for use in calculating the flow rate for each flow meter. The density meters can be based on measurements using a parallel pipe or using a microwave-based system, such as the STAR water-cut monitor (Texaco).

In one arrangement, the flow meters are based on venturis separated by a flow restriction and in an alternative arrangement the flow meters use orifice meters instead of venturis.

The orifice between the flow meters can be adjustable allowing the flow rate of the well to be altered at will and permitting well productivity to be calculated at different flow rates. In addition, it will be appreciated that in the flow meters which use orifices the flow meter orifices themselves can be adjustable to fine tune measurement of the various flow parameters.

According to the present invention there is provided apparatus for determining the flow rate of each phase of

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a multi-phase fluid in a pipe, said apparatus comprising;  
first and second spaced flowmeters for receiving said  
multi-phase fluid,

at least one flow restriction means associated with  
said first and said second flowmeters, and

fluid density measurement means coupled to said first  
and to said second flowmeters for measuring the density of  
said multi-phase fluid flowing therethrough, the  
arrangement being such that said apparatus is locatable in  
any spatial orientation to determine the flow rate in said  
multi-phase fluid.

Preferably said first and second flowmeters are  
located in series and separated by a flow restriction  
means. Conveniently, said flow restriction means is an  
orifice plate. Alternatively said first and second flow  
meters are connected in parallel, each of said first and  
second flowmeters being connected in series with a flow  
restriction means. Conveniently said flow restriction  
means is an orifice plate.

One flow restriction means is upstream of the first  
flowmeter and the other flow restriction means is  
downstream of the second flowmeter. Conveniently, the  
flowmeters are venturi flowmeters. Alternatively, the  
flowmeters are orifice meters.

According to one aspect of the present invention  
there is provided apparatus for determining the flow rate  
of a multi-phase fluid in a pipe, said pipe being adapted



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to be coupled to a source of hydrocarbon from a well, said apparatus comprising,

a first flow meter for connecting to a source of multi-phase fluid whose flow is to be measured,

a restriction orifice or choke located downstream of said first flow meter for receiving multi-phase fluid from said first flow meter,

a second flow meter located downstream of said restriction orifice or choke,

said first flow meter having at least two pressure sensors disposed along the length thereof for taking pressure measurements, fluid density measuring means associated with said first flow meter and with said second flow meter for measuring the density of fluid in said first and said second flowmeters, whereby, in use, the said at least two pressure sensors associated with said first flow meter and said density measuring means is used to determine the first bulk flow rate of said multi-phase fluid, and as the multi-phase fluid from said first flow meter passes through the choke the pressure reduces causing a gaseous phase to break from the oil phase increasing total fluid volume and velocity whereby said second flow meter with said at least two pressure transducers and said density measuring means provides measurement of the second bulk flow rate, said first and said second bulk flow rates being used to calculate the total flow of each phase and the flow rate of each phase

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flow rate at atmospheric conditions.

Preferably, the first and the second flow meters are venturi meters. Alternatively, the first and second flow meters are orifice meters.

Preferably also, the first and second venturi or orifice flow meters use three pressure transducers to monitor pressure therealong.

Conveniently, the density measuring means is a parallel pipe with two or more pressure sensors to provide an indication of density. Preferably though the density meter is a microwave-based measurement system and one density meter is associated with each flow meter.

Conveniently, the density meter is a microwave-based system, for example the STAR water-cut monitor marketed by Texaco.

Conveniently, also the orifices in the orifice-based flow meters are adjustable to regulate the flow rate.

Conveniently, both first and second flow meters in the choke are located in a single section of pipe.

According to a further aspect of the present invention there is provided a method of determining the method of measuring the flow rate of a multi-phase fluid in a pipe, said method comprising the steps of passing the fluid whose flow rate is to be measured through a first flow meter, measuring the density of the fluid and the pressure differential using a venturi or orifice meter and determining the flow rate of the fluid, passing the fluid

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from the first flow meter through a restriction orifice or choke to a second flow meter, said fluid when passed through said choke being at a reduced pressure such that the gas phase breaks from the oil phase whereby total fluid volume increases and the velocity increases,

measuring the density and differential pressure in the second flow meter and using these values to determine the flow rate in the second flow meter,

comparing the flow rates through the first and second flow meters and using the results of the comparison, together with the change of water/oil ratios and providing an absolute flow rate measurement for the multi-phase fluid at atmospheric conditions.

Preferably, the method includes passing the fluid through a first venturi, through a restriction orifice and then through a second venturi in series and in line with the first venturi. Alternatively, the fluid is passed through a first orifice meter having a restriction orifice and providing measurement transducers on either side of the orifice to calculate the pressure differential along the orifice meter and combining value of density together with the pressure differential to calculate the flow rate. Repeating this for the second flow meter when it is also an orifice meter.

Advantageously, three pressure measurements may be taken at various points in each flow meter, although it will be appreciated that two pressure measurements from

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each flow meter are sufficient to provide a pressure differential for use with Bernoullis equation together with density of the liquid in order to calculate the flow rate through a particular flow meter.

These and other aspects of the invention will become apparent from the following description when taken in combination with the accompanying drawings in which:-

Fig. 1 is a diagrammatic representation in accordance with a first embodiment of a multi-phase flow meter in accordance with the present invention;

Fig. 2 is a diagrammatic view of an alternative embodiment of a multi-phase flow meter;

Figure 3 is a graph of the water/oil ratio percentage versus pressure;

Figure 4 is a graph of bulk flow rate versus pressure for the oil, water and gas;

Figure 5 is a diagrammatic view of an alternative embodiment of the present invention;

Fig. 6 is a schematic diagram of a mobile process equipment package which is required to test exploration and appraisal of wells, and

Fig. 7 is a schematic diagram of an equivalent package to that in Fig. 6 utilising the multi-phase flow meter according to the embodiment of present invention shown in Figure 1.

Reference is first made to Fig. 1 of the drawings which depicts a first embodiment of a multi-phase flow

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meter which consists of a pipe section generally indicated by reference numeral 10 and which has a pipe wall 12 which defines a first venturi flow meter indicated by reference numeral 14, a restriction orifice or choke 16 and a second venturi flow meter indicated by reference numeral 18.

Elements 14, 16, 18 are in series with first flow meter 14 being the upstream flow meter which is connected to a supply of well test fluid (not shown) such as an outlet from a test tree on the rig floor. It will be appreciated that the venturi 14 and 18 are formed by restrictions in the wall of the pipe 10. The first flow meter has three pressure transducers 20, 22 and 24 located in the pipe wall for taking pressure measurements from positions P1, P2 and P3 and, similarly, flow meter 18 has three pressure transducers 26, 28 and 30 for taking measurements at positions P4, P5 and P6. It will be appreciated that the pressure measurements taken from positions P1, P2 and P3 and also P4, P5 and P6 record the momentum change (pressure difference) of the fluid and thus the velocity of fluid flow can be calculated from Bernoulli's equation;

$$\Delta p = \frac{\rho v^2}{2g}$$

Where:  $p$  is the differential pressure measured  
 $\rho$  is the density of the fluid in the flowmeter  
 $g$  is a gravitational constant, and

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v is the velocity of the fluid in the flowmeter

Thus rearranging the equation gives,

$$v = \sqrt{\frac{\Delta p 2g}{\rho}}$$

The density and the water/oil mixture (water cut) of the fluid flowing via the first restriction, i.e. the venturi neck, can be determined by using a density meter 32 such as a microwave based STARCUT water monitor (Texaco). Similarly, a second density meter 34 is coupled to the second flow meter 18 for measuring the density of fluid within this flow meter.

With the differential pressure measurements created by the venturi and sensed using transducers 20, 22 and 24 in the first flow meter or transducers 26, 28 and 30 in the second transducer together with the density measurements from density meters 34 and 36, it is possible, by Bernoullis equation, to establish a mass or bulk flow rate.

In operation, well fluid flows into the multi-phase transducer and, in particular, firstly through the first flow meter 14. The differential pressure created by the first venturi and measured at positions P1 and P2 or P2 and P3 is used to record a momentum change and thus the

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velocity of the fluid flow. Similarly, the density meter or the microwave density meter 34 provides a value of density and water/oil ratio and the use of the velocity and density rate is used to provide a value of the bulk flow rate through the first flow meter.

Fluid leaving the first flow meter passes through the choke 16 which is in fact a small orifice in the pipe and fluid passing through the orifice enters the second flow meter 18. As the fluid leaves the choke 16 the pressure reduces and this causes the gas phase within the multi-phase fluid to break from the oil phase whereby the total fluid volume increases and the velocity increases. The fluid in the second flow meter then passes via a second venturi restriction and the differential pressure created in the second flow meter is measured by transducers 26, 28 and 30 or pairs of transducers such as P4 and P5 or P5 and P6 to create a differential pressure value. The differential pressure value which is measured is used together with the value of the density and water/oil ratio obtained by the second density meter 34 to create a second bulk flow rate value. The density meter value is used to establish a percentage relation in oil rate/versus pressure drop. Additionally, if a microwave density meter is used, this will establish total liquid production at each meter, and comparison of upstream and downstream gavities and mass flowrate will provide an

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accurate gas flow rate.

The first and second bulk flow rate values are compared and simultaneously the change of water/oil ratios are also compared. The oil/water ratios (%) are related to pressure and these can be calculated from the graph shown in Figure 3. This means that the flow of each separate phase can be calculated by extrapolation from the values using the graph shown in Figure 4 to provide a bulk flow rate value for each fluid phase of the multi-phase fluid at atmospheric conditions (15 p.s.i.). Therefore the increase in gas flowrate equals the difference between the bulk flow rates plus the reduction in oil rate and the reduction in oil rate equals the difference in oil/water ratios. The gas and oil rate can be calculated by using an algorithm to the oil/water ratios and bulk flow rate values. The algorithms, which are not part of this invention, are derived from a database constructing from a large amount of measured data. Curve fitting programmes are used to provide comparisons between the measured data and the database to provide individual flowrates for each phase. This will enable the database and the algorithms to be updated continuously. In particular from Figure 5 it will be seen that as the pressure falls the bulk flow rate of oil decreases whilst that for gas increases, water remaining constant. Thus means that the percentage of water to oil increases in the mixture. At around 2000psi



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there is about 20 % water whereas at 15psi (atmospheric conditions) there is about 40 % water in the fluid mixture.

Reference is now made to the embodiments shown in Fig. 2 of the drawings which is similar to that shown in Fig. 1 except that the venturi flow meters are replaced by orifice meters generally indicated by reference numerals 36 and 38. It will be appreciated that like numerals refer to like parts in this embodiment. As with the venturi meter the orifice meters create a pressure differential which is measured upstream and downstream of the meter by pressure sensors P1 and P2 or P1 and P3 for the first orifice meter 36 and by P4 and P6 or by P5 and P6 for the second orifice meter 38. As with the embodiment in Fig. 1 these orifice meters and the density meters 32 and 34 provide bulk flow rate values through the first and second flow rate meters 36 and 38 enabling an absolute flow rate and atmospheric conditions to be determined using the structure of this embodiment.

Reference is now made to figure 5 of the drawings which depicts an alternative embodiment of a multi-phase flowmeter in accordance with the present invention. In this case two fluid flowmeters with associated flow restriction orifices are connected in parallel instead of in series.

Hydrocarbons from the well pass through pipe 100

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which splits into two pipes 102, 104 which feed venturi flowmeters 106, 108 respectively. Each pipe 102, 104 carries 50 % of the flow.

In order to calculate the flow rate of each phase at atmospheric conditions, it is necessary to obtain at least 2 values of bulk flow rate and water/oil percentage to be able to extrapolate the measured data as described above. This is achieved by locating restrictive orifices or chokes 110, 112 in series with the flowmeters 106, 108 respectively.

A pressure sensor  $P_{11}$  measures pressure at the inlet position  $P_1$  to the orifice 110 and, as in the Figure 1 embodiment, the venturi flowmeter has three pressure transducers  $P_{12}$ ,  $P_{13}$  and  $P_{14}$  in the pipe wall at positions  $P_2$ ,  $P_3$  and  $P_4$ . The density of fluid at the inlet and outlet is measured using STARCUT water monitors 114, 116 respectively and, using these values and Bernoulli's equation, the bulk flow rate in venturi flowmeter 106 can be calculated. This is repeated for orifice 112 and flowmeter 108 using pressure measurements for  $P_{21}$ ,  $P_{22}$ ,  $P_{23}$  and  $P_{24}$  at positions  $P_1$ ,  $P_2$ ,  $P_3$  and  $P_4$  and density values for STARCUT density meters 118, 120 respectively.

It will be appreciated that flowmeter 106 gives the effective flow rate of 50 % the well at upstream orifice conditions whereas flowmeter 108 provides effective flow at downstream orifice conditions.

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It will be appreciated that various modifications may be made to the embodiments hereinbefore described without departing from the scope of the invention. For example, it will be appreciated that in the embodiments of Fig. 1 and Fig. 2 an adjustable choke disposed between the first and second flow meters can be used with the adjustment allowing the flow rate of the well to be altered enabling well productivity to be established at different flow rates. This also permits the flow to be conveniently controlled to enable the measuring system to operate in its most efficient range. Adjustable chokes can also be used with the Figure 5 embodiment. It will also be appreciated that, in each embodiment, the flow meters can be venturi meters or orifice meters or a combination of these. It will also be appreciated that although three pressure transducers are shown in each of the embodiments in Fig. 1 Fig. 2 and Figure 6 for the venturi flowmeters, each flow meter may use only two transducers to determine the pressure differential to calculate flow velocity. In addition, it will be appreciated that various other types of density meters may be used instead of a microwave-based system, for example, a parallel tube with two separate pressure sensors which is well known in the art.

In addition, it will be appreciated that the orifices in the first and second flow meters in Fig. 2 may be adjustable to further vary the flow rate.

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It will be appreciated that the present invention provides a significant advantage in that the bore through which the hydrocarbon product flows is not obstructed by any component of the meter as is the case if the meter comprises a propeller or impeller which is rotated by movement of fluid past it. The lack of obstruction in the pipe makes the system far less susceptible to erosion or plugging which may result from unconsolidated formation particles and accuracy of measurement. In addition, the system can be used on the surface in any spatial orientation and can be readily connected to an existing fluid outlet from a conventional tree, thus minimising the necessity to run tools into wells which is both time consuming, expensive and which is more hazardous. The embodiment shown in Figure 6 is particularly compact and is suitable for use on sites where space is restricted. The use of separate meters with each flowmeter improves the accuracy of phase flow rate calculations.

It will be appreciated that the use of a multi-phase flow meter in accordance with the present invention provides a substantial reduction in off-shore process equipment. For example, Fig. 6 depicts a schematic diagram of an existing mobile process package which is utilised to test exploration wells and also to appraise existing wells. It should be understood that all of this equipment has to be transported between the rig and shore

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each time it is used which is, as mentioned above, time consuming and expensive. In contrast, the schematic diagram of Fig. 7 depicts an equivalent bio-process package incorporating a multi-phase flow meter in accordance with the Figure 1 embodiment of the present invention. It will be seen that the resultant reduction in equipment offers a large reduction in both manpower requirements and hazardous situation over the existing system.

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## CLAIMS

1. Apparatus for determining the flow rate of each phase of a multi-phase fluid in a pipe, said apparatus comprising;

first and second spaced flowmeters for receiving said multi-phase fluid,

at least one flow restriction means associated with said first and said second flowmeters, and

fluid density measurement means coupled to said first and to said second flowmeters for measuring the density of said multi-phase fluid flowing therethrough, the arrangement being such that said apparatus is locatable in any spatial orientation to determine the flow rate in said multi-phase fluid.

2. Apparatus as claimed in claim 1 wherein said first and second flowmeters are located in series and separated by a flow restriction means.

3. Apparatus as claimed in claim 1 or claim 2 wherein said flow restriction means is an orifice plate.

4. Apparatus as claimed in claim 1 wherein said first and second flow meters are connected in parallel, each of said first and second flowmeters being connected in series with a flow restriction means.

5. Apparatus as claimed in claim 4 wherein said flow restriction means is an orifice plate.

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6. Apparatus as claimed in claim 5 wherein one flow restriction means is upstream of the first flowmeter and the other flow restriction means is downstream of the second flowmeter.

7. Apparatus for determining the flow rate of a multi-phase fluid in a pipe, said pipe being adapted to be coupled to a source of hydrocarbon from a well, said apparatus comprising,

a first flow meter for connecting to a source of multi-phase fluid whose flow is to be measured,

a restriction orifice or choke located downstream of said first flow meter for receiving multi-phase fluid from said first flow meter,

a second flow meter located downstream of said restriction orifice or choke,

said first flow meter having at least two pressure sensors disposed along the length thereof for taking pressure measurements, fluid density measuring means associated with said first flow meter and with said second flow meter for measuring the density of fluid in said first and said second flowmeters, whereby, in use, the said at least two pressure sensors associated with said first flow meter and said density measuring means is used to determine the first bulk flow rate of said multi-phase fluid, and as the multi-phase fluid from said first flow meter passes through the choke the pressure reduces

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causing a gaseous phase to break from the oil phase increasing total fluid volume and velocity whereby said second flow meter with said at least two pressure transducers and said density measuring means provides measurement of the second bulk flow rate, said first and said second bulk flow rates being used to calculate the total flow of each phase and the flow rate of each phase flow rate at atmospheric conditions.

8. Apparatus as claimed in claim 7 wherein the first and the second flow meters are venturi meters.

9. Apparatus as claimed in claim 7 wherein the first and second flow meters are orifice meters.

10. Apparatus as claimed in any one of claims 7, 8 or 9 wherein the first and second venturi or orifice flow meters use three pressure transducers to monitor pressure therealong.

11. Apparatus as claimed in any one of claims 7 to 10 wherein the density measuring means is a parallel pipe with two or more pressure sensors to provide an indication of density.

12. Apparatus as claimed in claim 11 wherein the density meter is a microwave-based measurement system and one density meter is associated with each flow meter.

13. Apparatus as claimed in any one of claim 9 to 12 wherein the orifices in the orifice-based flow meters are adjustable to regulate the flow rate.



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14. Apparatus as claimed in any one of claims 7 to 13 both first and second flow meters in the choke are located in a single section of pipe.

15. A method of determining the method of measuring the flow rate of a multi-phase fluid in a pipe, said method comprising the steps of passing the fluid whose flow rate is to be measured through a first flow meter, measuring the density of the fluid and the pressure differential using a venturi or orifice meter and determining the flow rate of the fluid, passing the fluid from the first flow meter through a restriction orifice or choke to a second flow meter, said fluid when passed through said choke being at a reduced pressure such that the gas phase breaks from the oil phase whereby total fluid volume increases and the velocity increases,

measuring the density and differential pressure in the second flow meter and using these values to determine the flow rate in the second flow meter,

comparing the flow rates through the first and second flow meters and using the results of the comparison, together with the change of water/oil ratios and providing an absolute flow rate measurement for the multi-phase fluid at atmospheric conditions.

16. A method as claimed in claim 15 including the step of passing the fluid through a first venturi, through a restriction orifice and then through a second venturi in series and in line with the first venturi.

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17. A method as claimed in claim 15 including the step of passing the fluid through a first orifice meter having a restriction orifice and providing measurement transducers on either side of the orifice to calculate the pressure differential along the orifice meter and combining value of density together with the pressure differential to calculate the flow rate.

18. A method as claimed in claim 17 including the step of repeating this for the second flow meter when it is also an orifice meter.

19. A method of determining the flow rate of each component of a multi-phase fluid flowing in a pipe, said method comprising the steps of,  
passing the fluid through first and second flowmeters, and through at least one restriction orifice associated with said first and second flowmeters,  
measuring the density of the fluid passing through each flowmeter,  
measuring pressure differentials across said first and second flowmeter,  
denoting the bulk flow rate through said first and said second flowmeters,  
comparing said bulk flowmeters and, using the results of said comparison, and the information about the change of water/oil ratios, and providing a value of flow rate measurement of each phase of the multi-phase fluid at atmospheric conditions.

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20 A method as claimed in claim 19 wherein said method comprises the step of passing said multi-phase fluid through first and second flowmeters in parallel, with substantially half of the total fluid passing through each flowmeter.

21. A method as claimed in claim 20 wherein one half the fluid is passed through a first flow restriction orifice upstream of said first flowmeter and the other half of the fluid is passed through a second flow restriction orifice downstream of said flowmeter.

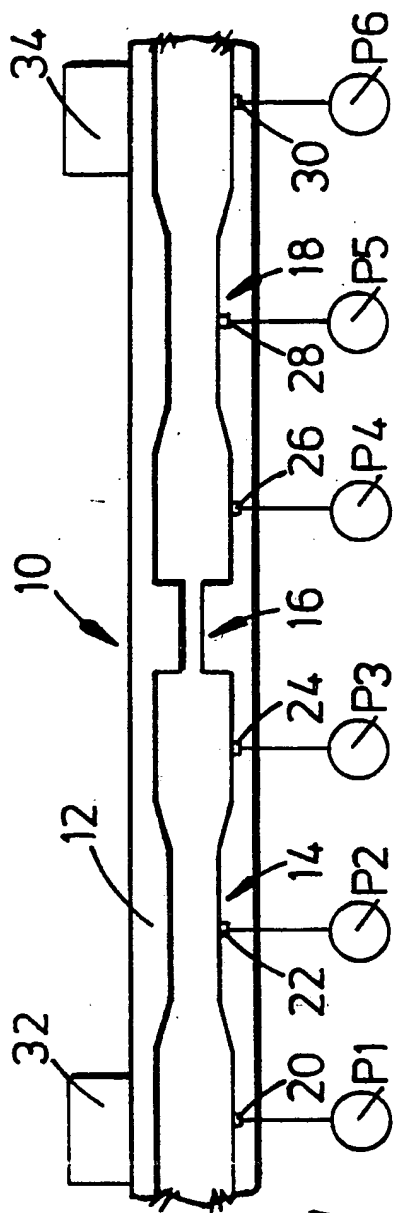


FIG. 1

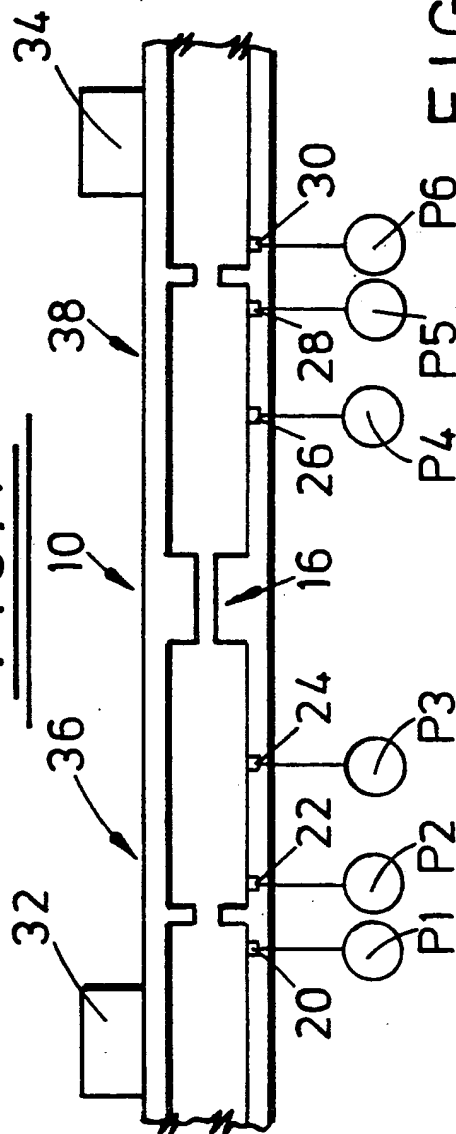
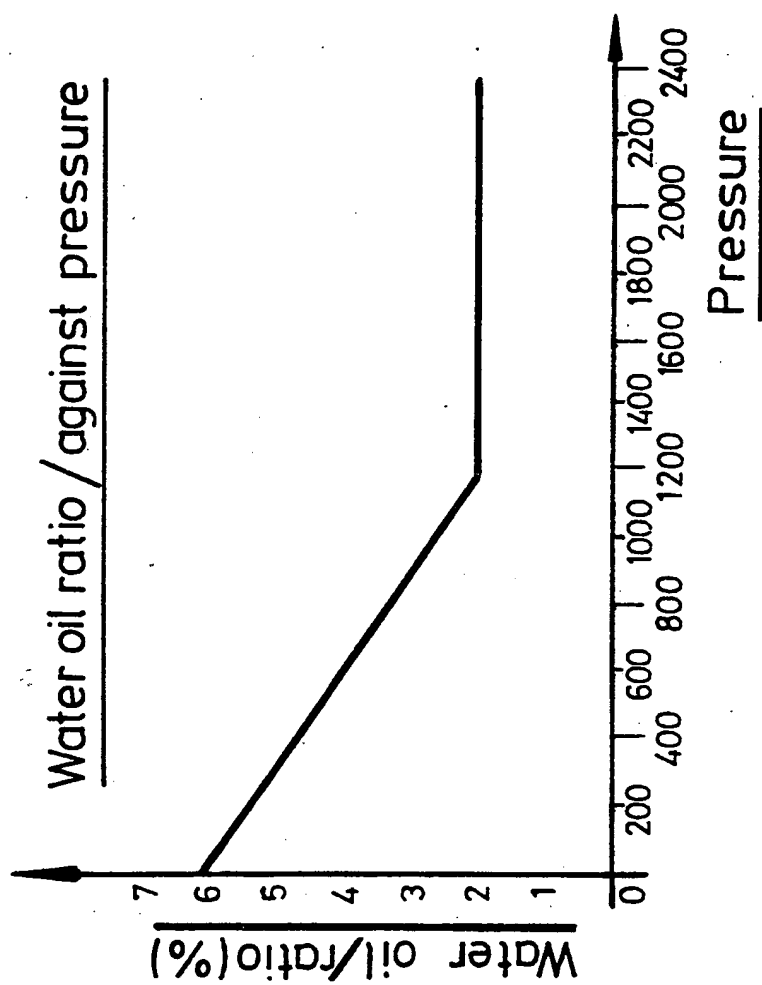
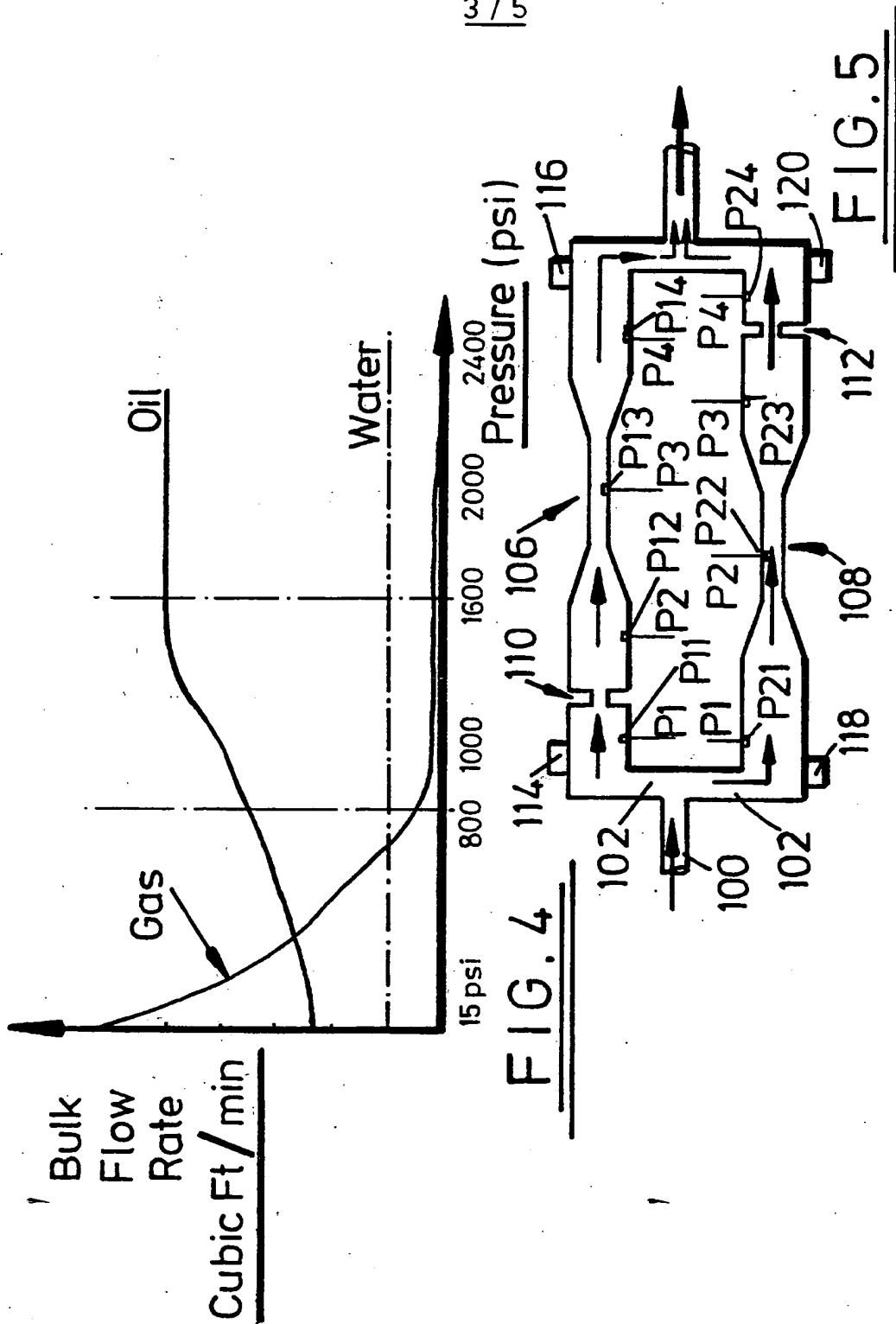
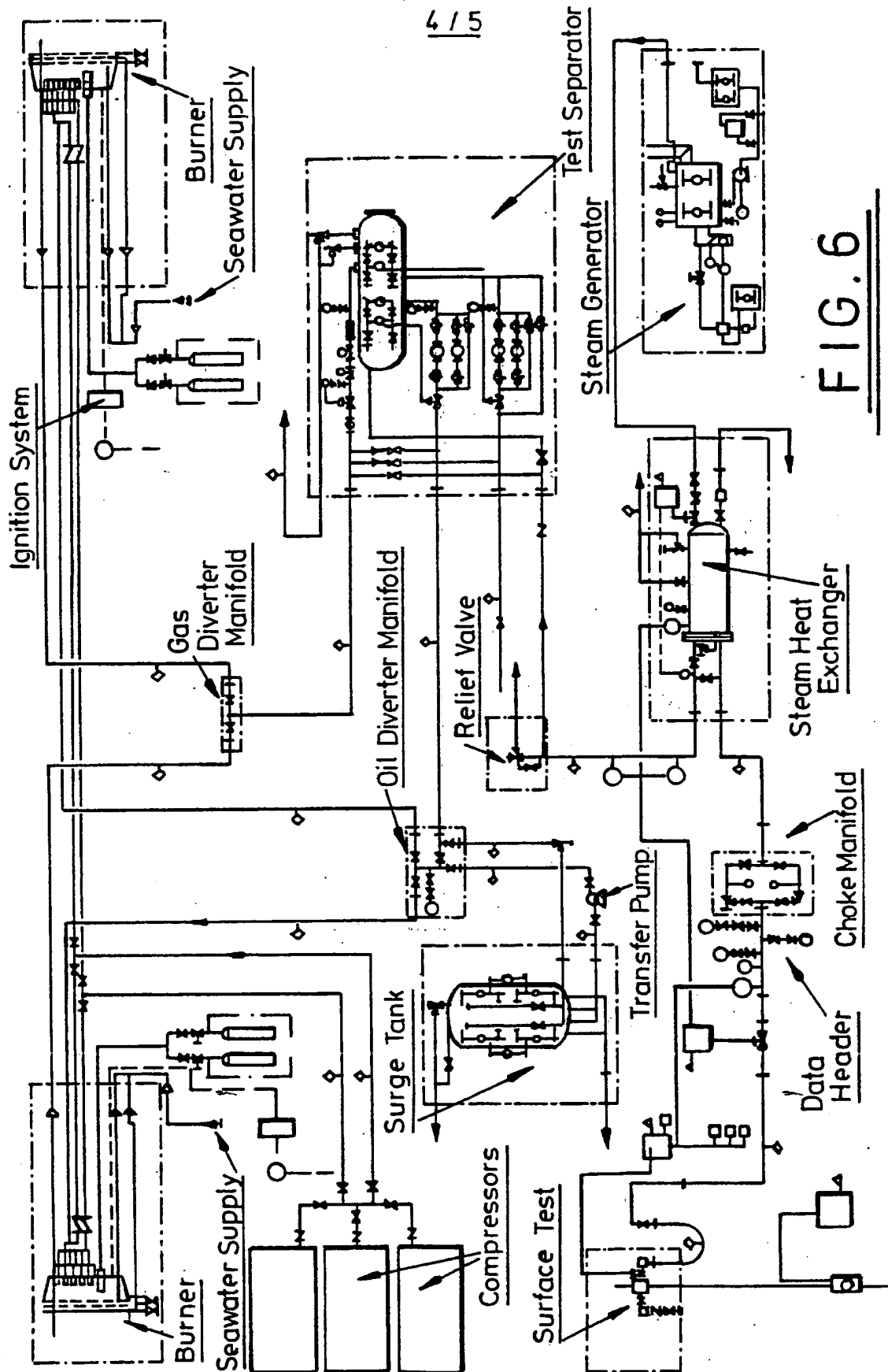


FIG. 2

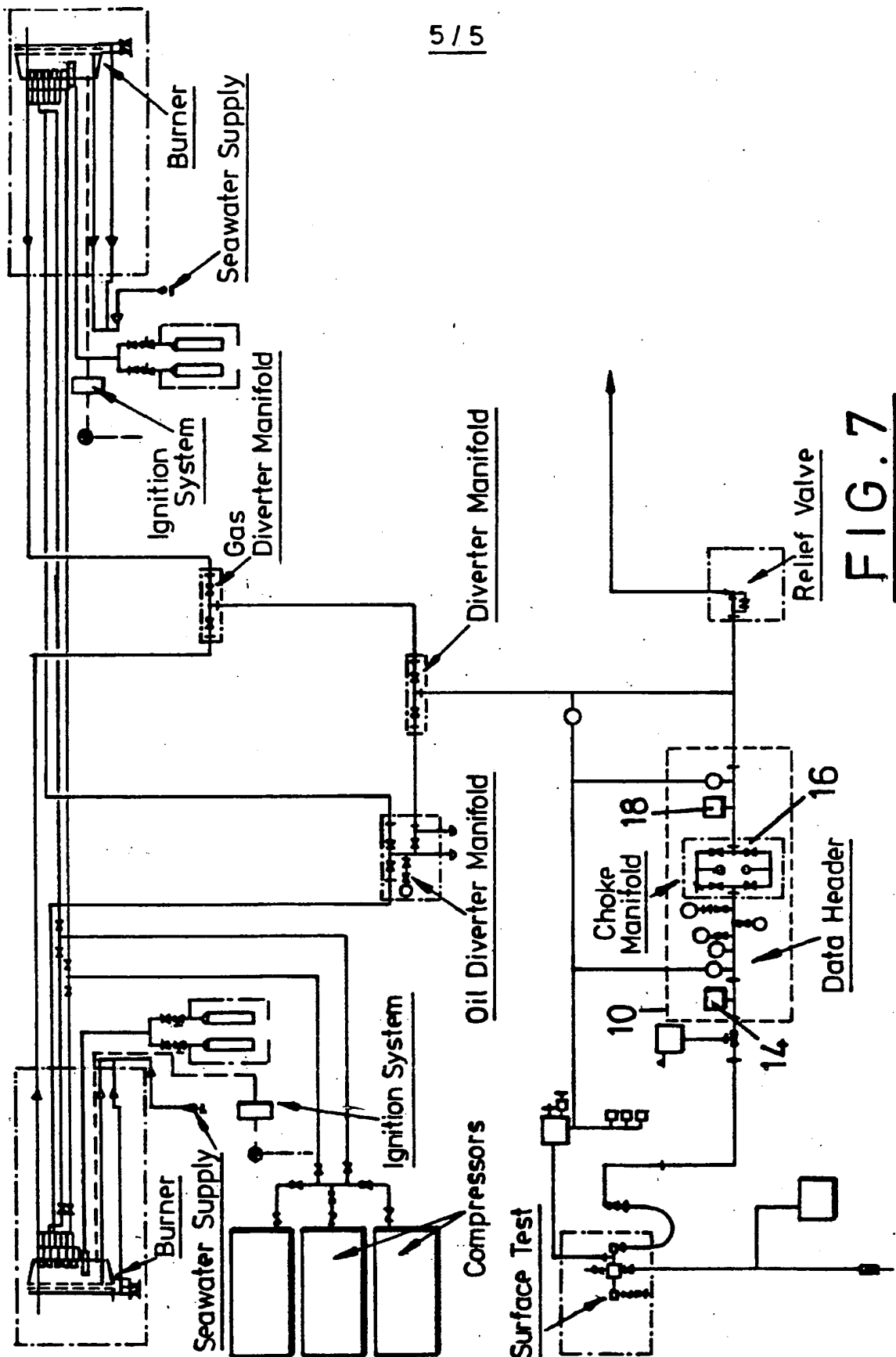
2 / 5FIG. 3

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**FIG. 6**

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**FIG. 7**



# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 94/01442

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 G01F1/74

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO,A,91 15738 (J. AGAR) 17 October 1991 cited in the application see page 5, paragraph 2 - page 10, last paragraph; figures 1-3 ---	1-21
A	DE,A,32 22 727 (NAGASAKA) 10 February 1983 see page 11, last paragraph - page 12, last paragraph; figure 16 ---	1
A	DE,A,29 25 510 (CARL SCHENCK) 15 January 1981 see page 7, paragraph 3 - page 8, last paragraph; figure 2 ---	9,17
	--- -/-	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

13 September 1994

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# INTERNATIONAL SEARCH REPORT

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PCT/GB 94/01442

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 7, no. 270 (P-240) (1415) 2 December 1983 & JP,A,58 151 517 (SUMITOMO) 8 September 1983 see abstract ---	8,10,12
A	FR,A,2 386 021 (FLOPETROL) 27 October 1978 see page 1, line 1 - line 7 see page 2, line 28 - page 3, line 21 see page 4, line 1 - page 5, line 5 see page 8, line 11 - page 9, line 35; figure 2 ---	1
P,A	WO,A,93 17305 (SCHLUMBERGER) 2 September 1993 see the whole document ---	1-21
P,A	GB,A,2 263 172 (PECO) 14 July 1993 see page 7, paragraph 1 -paragraph 2; figure 1 -----	1,7,8

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 94/01442

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A-9115738	17-10-91	US-A- 5099697 AU-A- 7446591 CN-A- 1055423 EP-A- 0523068	31-03-92 30-10-91 16-10-91 20-01-93
DE-A-3222727	10-02-83	NONE	
DE-A-2925510	15-01-81	NONE	
FR-A-2386021	27-10-78	DE-A- 2812715 JP-A- 54001094 US-A- 4168624	05-10-78 06-01-79 25-09-79
WO-A-9317305	02-09-93	AU-B- 3638493	13-09-93
GB-A-2263172	14-07-93	NONE	